Real World Accident Analysis of Car-to-Car Intersection Near-Side Impacts: Focus on Pelvis Injury

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ABSTRACT

Near-side impacts are one of the severe crash modes of all the impacts. Even though 90% of vehicles have achieved "Good" in IIHS rating, there is hardly any sign of decreasing trend in side impact fatalities for last few years. IIHS is planning to introduce a new test protocol because even the cars with “Good Rating” in IIHS tests can still have AIS3+ injuries. In side impacts, a higher number of severe injuries were found in thorax, head and then followed by pelvic region. Though many researchers addressed the mechanism of thorax and head injuries, there are a few in-detail accident analysis of pelvis injuries. Pelvis injury often leads to significant medical expense and impacts the long-term quality of life. This study is focused to find out (i) the relation between pelvis injury with structural deformation (ii) the frequency and the type of pelvis injuries (iii) the type of target of population to considered (size: small/large, gender: male/female) with the help of accident data and simulation results. C2C intersection accidents were selected from NASS-CDS (CY2004-15, n=913 cases) to identify the influential parameters by logistic regression. From the accident analysis it is found that a)pelvic ring fracture is one of the most frequent injuries, b)10 o’clock impact caused the highest number of injuries, c) pelvis injury frequency is more in female than male, and d) risk of pelvis injury increases when the maximum intrusion of B-pillar and surrounding door structure exceeds a certain level. Logistic regression indicates that angle of impact, location of impact and initial velocity of the struck car are also important parameters. To gain more benefit in real-world accidents by introducing future side impact protocols, a rational approach is necessary to focus more on evaluating the most frequent pelvic ring fracture by introducing more bio-fidelic dummy (say World-SID) in future protocol tests.

INTRODUCTION

Near-side (lateral impact location on driver side) impacts are one of the most severe crash modes with high frequency in real traffic accidents, commonly resulting in serious injuries (Randa, 2003[4], Matthew, 2015[5], Helena, 2011[2]). In SINCAP tests, at the time of impact, the barrier is moving at 62kph and “crabbed” 27 degrees toward the rear of the test vehicle to keep the front of the barrier parallel to the side of the test vehicle. The resulting change in velocity can vary within a range of 22 to 32kph, depending on the mass of the struck vehicle. Insurance Institute for Highway Safety (IIHS) side-impact crash tests consist of a stationary test vehicle struck on the driver’s side by a moving trolley fitted with a deformable honeycomb barrier for perpendicular impact. The leading end of the barrier is shaped to simulate the typical front end of a pickup or Sports Utility Vehicle (SUV). The 1,500kg moving deformable barrier strikes the vehicle on the driver’s side at a velocity of 50kph. Vehicles with high-hood front-end profile caused more head injuries in passenger vehicles in real world accidents and it could not be assessed with the FMVSS 214 barrier. As a result, the IIHS started its side test program in 2003 with a barrier designed to represent the front end of a typical SUV and pickup. Later, in the FMVSS No. 214, the oblique pole test was introduced. To simulate the real world accidents, the vehicle to be tested is propelled sideways into a rigid pole at an angle of 75 degrees with a speed of 32kph. Three different C2C related side impact protocols were given in Figure 1. For detail information of different NCAP test conditions and regulations of different countries refer to the Safety Companion [24] compiled by CARHS.

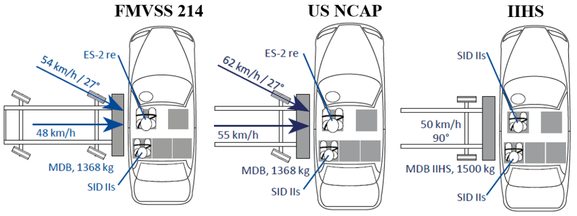


Figure 1. C2C related side impact protocols

Statistics showed that car-to-car(C2C) near side impacts account for more than 60-70% of side impact crashes resulting in serious-to-fatal injuries (Pal 2017[12]). Due to limited survival space on the struck side, near-side occupants, adjacent to the side of the vehicle subjected to major impact, frequently sustain severe injuries than far-side occupants. Occupant injury can be significantly affected by a different set of crash characteristics and the effects of a crash configuration such as impact direction, impact angle, and change in delta-V need to be studied in detail with real world accident data. Xinghua Lai et al., (2012[9]) investigated the effects of specific impact direction and impact regions on serious-to-fatal injuries of driver occupants involved in near-side collisions using data gathered from National Automotive Sampling System Crashworthiness Data System NASS-CDS (CY1995–2005, [1]) and found that the risk of serious injury was higher for side center (P) and side front distribution (Y) than the side front (F) or rear end (B) locations.

Even though 90% of vehicles have achieved "Good" in IIHS rating, there is hardly any sign of decreasing trend in side impact fatalities for last few years. IIHS is planning to introduce new tests because even the cars with “Good Rating” in IIHS tests can still have AIS3+ injuries. In side impacts, a higher number of severe injuries were found in thorax, head and then followed by pelvic region. Though many researchers addressed the mechanism of thorax and head injuries, [6,7,8], there are a few in-detail accident analysis of pelvis injuries. Pelvis injury often leads to significant medical expense and impacts the long-term quality of life. In order to improve occupant safety in C2C side impact intersection crashes, the objectives of this paper are to find out (i) the relation between pelvis injury with structural deformation (ii) the frequency and type of pelvis injuries and (iii) the type of target of population to considered (size: small/large, gender: male/female, BMI) with help of accident data, and simulation.

DATA & METHODS

This study used accident data from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) for the calendar year 2004 to 2015. Table 1 shows the assumptions used to prepare the accident data set for this study. The accident samples are limited to C2C intersection side imact planar collisions (i.e., excluded crashes with the primary general area of damage as top or bottom and rollovers). Values with unknowns have been omitted. In total, 913 vehicles were extracted to perform the accident analysis and logistic regression analysis [13]. Details of those analyses are described in later sections. Table 2 shows the final data set extracted from NASS-CDS CY 2004-15 using the criteria mentioned in Table1. In total, 913 occupants with 4195 injuries involved in near side impacts were selected with six collision deformation codes (F, P, Y, Z, D, B) and with three main impact angles (8-10 o'clock, driver side) as shown in Figure 2.

Table 1.
List of criteria for input dataset

General Area Damage1=Left
The direction of Force DOF=8-10 o'clock
Impact Location=F, P, Y, B, D, Z
Body Type PV (1-9,17)
Model Year>=2000
Driver Role=1, (Seat Position=11)
Age16+
V2V OBJCTD<=30
Towed Away Vehicles
No Ejection
No Rollover
No Fire Occurrence
Excluded AIS7 injury

Table 2.
List of dataset

	Raw data		Weighted	
	Total no	With pelvis-injury	Total no	With pelvis-injury
Drivers	913	203 (22.2%)	639280	131436 (20.5%)
Injuries	4195	291 (7.0%)	3359148	191858 (5.7%)

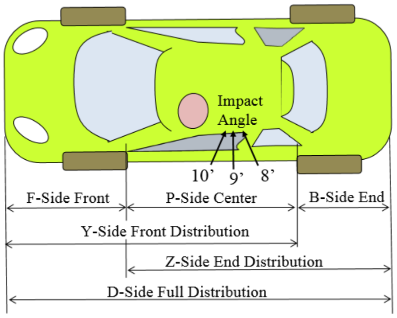


Figure 2. NASS-CDS collision deformation code (8, 9, 10 o'clock impact angles)

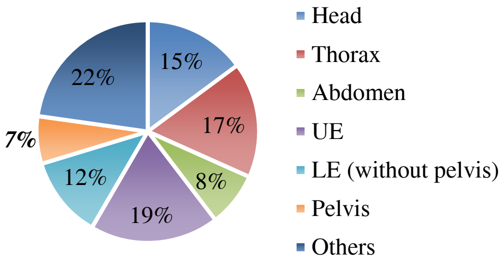
There were 203 cases on driver side impact involving pelvis injuries which account for 22.2% of overall side impact injury cases (Table 2).

RESULTS

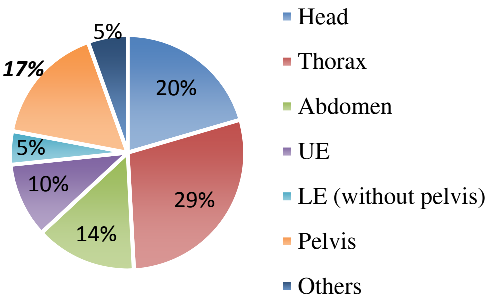
The pelvis injury pattern of occupants involved in C2C near side collisions is discussed in this section. The order of explanation is: a) first, an overview of pelvis region and distribution of injuries, the effect of b) impact angle, c) gender, and d) intrusion magnitude w.r.t pelvis injury. Logistic regression is performed to check the probability of pelvis AIS3+ and AIS2+ injuries occurrence using different factors such as lateral delta-V, gender, the angle of impact, BMI etc. Results were calculated using XLSTAT software[10, 11]. A separate sensitivity analysis was also performed, to see the effect of lateral delta-V and angle of impact and finally, the pelvis injury results were verified using human body simulations. In this study, all the logsitic regression models developed using weighted data.

Overview of side impact injuries

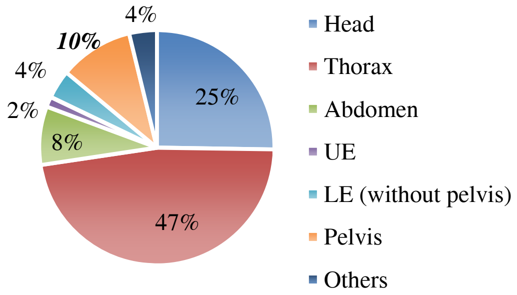
Figure 3 shows the number of injuires in different body regions for three AIS level of severity in nearside impacts. Pelvis AIS1+, AIS2+, and AIS3+ injuries account for 7%, 17%, and 10%, respectively of overall near side impact injuries. The percentage of head and thorax injuries are increasing as the AIS level increases.



a) AIS1+ injuries



b) AIS2+ injuries



c) AIS3+ injuries

Figure 3(a, b, c). Number of AIS injuries in different body regions of near side impacts

Overview of pelvic region and related injuries

Figure A1 shows the important parts associated with the pelvis and they are lumbar spine (cord, disc), sciatic nerve, pelvis ring, acetabulum, sympysis pubis, hip joint, and sacroilliac. Table A1 shows the count of AIS1+, AIS2+ and AIS3+ injuries of each individual sub-parts. AIS2+ and AIS3+ injuries constitute 16.5% (233) and 10.2% (72) of overall side impact injuries. It is interesting to find that, when one plots (refer Figure 4) the percenatge of pelvis related AIS injuries as mentioned in Figure A1 and Table A1, AIS2+ was highest. 75% of those AIS2+ injuries were pelvis ring fracture(refer Figure 5). Hence, together with AIS3+, AIS2+ pelvis injuries need some attention in the future. Note that the percenatge is calculated with respect to different AIS levels among the injuries of different body regions when pelvis injury occurred.

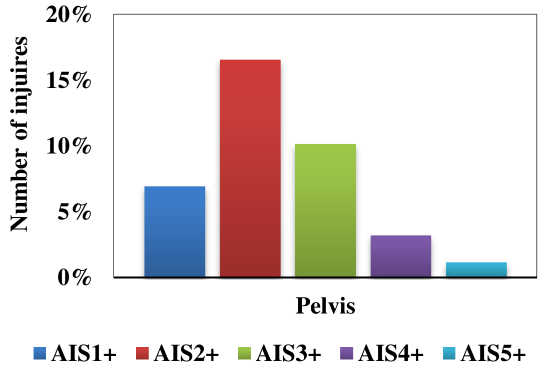


Figure 4. Percentages of pelvis injury across different AIS levels within the injuries of various body regions, when pelvis injury occurred.

Figure 5 shows the distribution of different injuries in each part of the pelvis region. It is found that the pelvic ring fracture (60%) is the most frequent compared to all the injuries and then followed by lumber spine (cord+disc, 31%) injuries. Symphysis pubis fracture is also one of the common injuries wihtin the pelvis region.

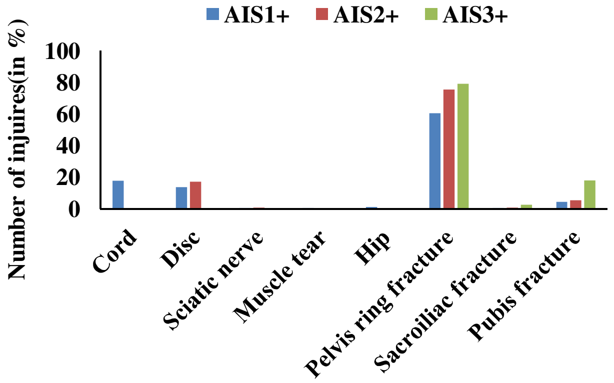


Figure 5. Distribution of pelvis injuries

Effect of angle of impact

Figure 6 shows the effect of angle of impact on the pelvis injuires for different AIS injury levels. It is observed that the oblique 10 o'clock impact angle caused the maximum no. of injuries when compared with those of 9 o'clock and 8 o'clock impacts.

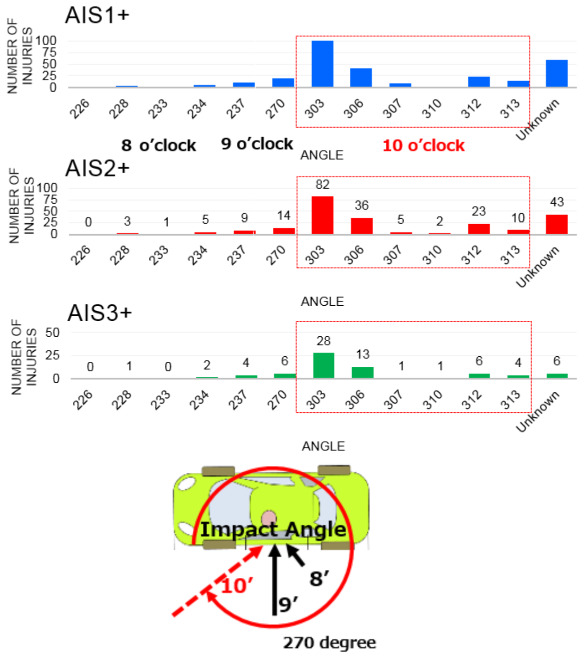


Figure 6. Variation of pelvis injury w.r.t angle of impact. (255~285 deg. corresponds to 9 o'clock)

This shows that most of the real world side injuries are due to oblique impact but not caused by perpendicular impact. The angle of impact of each case is verified by the ratio of delta-V (longitudinal and lateral components) as mentioned in the accident report. The present real accident data clearly indicates that in future test protocol, proper consideration has to be given about the angle of impact during the loading phase of the pelvis in dummies to capture the real world phenomena.

Effect of gender

Figure 7 shows the effect of gender on the pelvis injury. It is observed that female were having more number of injuires than male. This shows that female were most likely to have higher pelvis injuries than male. Some of the possible reasons may be that (i) the females sit further forward towards the steering wheel than males who are usually taller in height than females (refer Figure A6) and (ii) the shape and strength of pelvis are different. It is to be noted that the pelvis injury is influenced by trochanteric soft tissue thickness and BMD of female occupants [15].

Logistic models: lateral delta-V, gender, and angle of impact

Logistic regression is peformed to check the probability of pelvis AIS3 and AIS2+ injury occurance using different factors such as lateral delta-V, gender, and angle of impact.

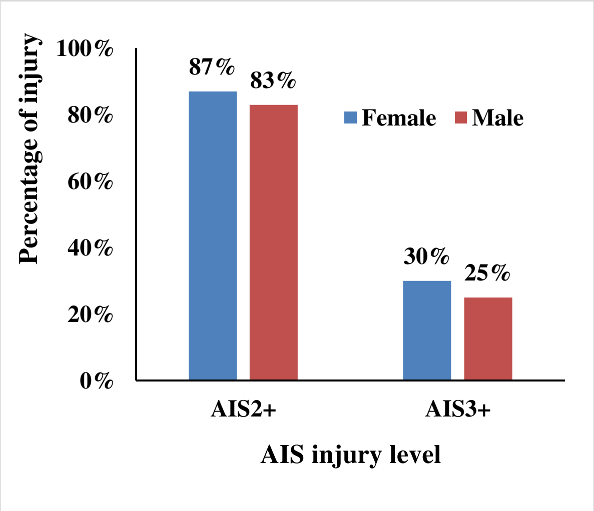


Figure 7. Variation of injuries w.r.t gender

Results of logistc regression were mentioned in Table 3 and Table 5 with AIS3+ and AIS2+ pelvis injury as dependent variables. All the probability values are calculated by varying the lateral delta-V for two 9 o'clock and 10 o'clock impact angles. As shown in Figures 8 and 10, it is clearly evident that the probability curve for 10 o'clock impact is above the 9 o'clock impact curve for both AIS3+ and AIS2+ injuries. The probability of AIS3+ injury is higher for 10 o'clock impact than 9 o'clock impact. Table 4 and 6 show the typical examples of the change in probability values for 10 and 9 o'clock impacts with respect to lateral delta-V changes. At 25kph (equiv. to 50kph barrier impact) and 30kph (equiv. to 60kph barrier impact) lateral delta-V, the probability values changes from 5.5% to 17.38% (3.16 times) and 8.87% to 26.04% (2.93 times) for inclined 10 o'clock and perpendicular 9 o'clock impacts, respectively.

Table 3.
Logistic Model when predicting pelvis AIS3+

n=221, Pelvis AIS3+(0:158,1:63)	Value	Pr. > Chi²	Odds ratio
Intercept	-11.911	< 0.0001	
Ln(Lateral delta-V)	2.826	< 0.0001	16.88
Gender Male: 0	0.000		
Gender Female: 1	-0.030	0.945	0.970
Angle 9 o'clock: 0	0.000		
Angle 10 o'clock: 1	1.286	0.007	3.617

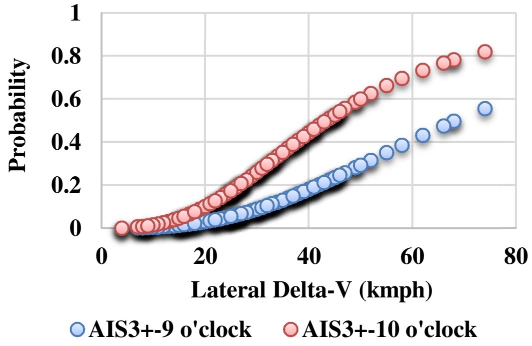


Figure 8 Comparison of probability of AIS3+ for 10 and 9 o'clock impacts with respect to lateral delta-V.

Table 4.
Example of the probabilities of AIS3+ of 10 and 9 o'clock impacts with respect to change in lateral delta-V from 25kph to 30kph

Lateral delta-V (kph)	**9 o' clock impacts**	**10 o' clock impacts**	**Ratio of 10→9 o'clock impacts**
25	5.50%	17.38%	**3.16**
30	8.87%	26.04%	**2.93**
Probability ratio of 30→25kph change in delta-V	**1.61**	**1.50**	Effect of angle is more than 5kph delta-V increase

Table 5.
Logistic Model when predicting pelvis AIS2+

n=221, Pelvis AIS2+(0:41,1:180)	Value	Pr. > Chi²	Odds ratio
Intercept	-19.137	< 0.0001	
Ln(Lateral delta-V)	6.481	< 0.0001	652.5
Gender Male: 0	0.000		
Female: 1	-2.912	< 0.0001	0.054
Angle 9 o'clock: 0	0.000		
10 o'clock: 1	2.466	< 0.0001	11.777

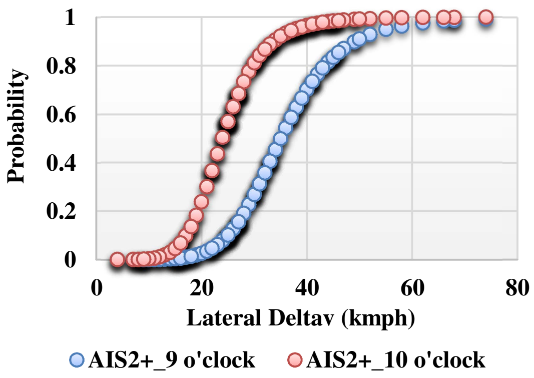


Figure 9. Comparison of probability of AIS2+ for 10 and 9 o'clock impacts with respect to lateral delta-V.

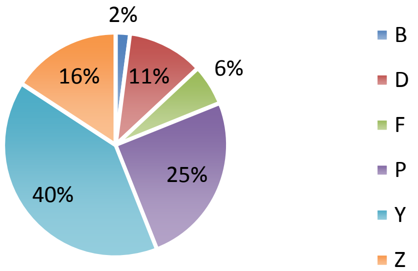
Table 6.
Example of the probabilities of AIS3+ of 10 and 9 o'clock impacts with respect to change in lateral delta-V from 25kph to 30kph

Lateral delta-V (kph)	**9 o' clock impacts**	**10 o' clock impacts**	**Ratio of 10→9 o'clock impacts**
25	10.08%	56.91%	**5.64**
30	26.76%	81.15%	**3.03**
Probability ratio of 30→25kph change in delta-V	**2.65**	**1.43**	Effect of angle is more than 5kph delta-V increase

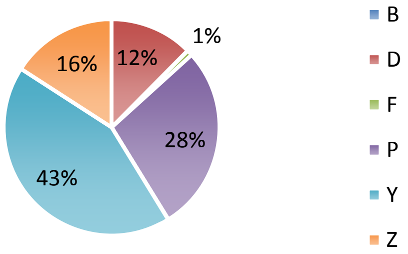
Similar results were observed when predicted with AIS2+ injury level (refer to Table 5, 6 and Figure 9).

Effect of impact location (CDC code)

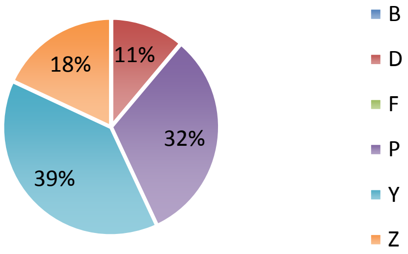
Figure 10(a,b,c) shows the number of pelvis injuries with respect to the location of impact. Y region had the highest number (for AIS1+: 40%, AIS2+: 43%, AIS3+: 39%) of injuries compared to other locations and then followed by P and Z locations. Combined Y and P locations cover more than $2/3^{rd}$ of all injuries from AIS1-3.



a) AIS1+ pelvis injuries



b) AIS2+ pelvis injuries



c) AIS3+ pelvis injuries

Figure 10 (a, b, c). Number of AIS injuries with respect to the location of impact (based on CDC code)

Effect of impact location (from crash pictures)

In order to estimate more accurately the effect of impact location, BMI and intrusion magnitude, the number of cases were increased from 203 (driver alone) to 265 by adding pelvis injury of right side passengers cases also(Figure 11). By detail inspection of damage pictures of each case in the

NASS-CDS database, one could identify the location of impact from B pillar accurately. This will help one to estimate the changes of injury pattern with respect to the impact location of maximum external deformation.

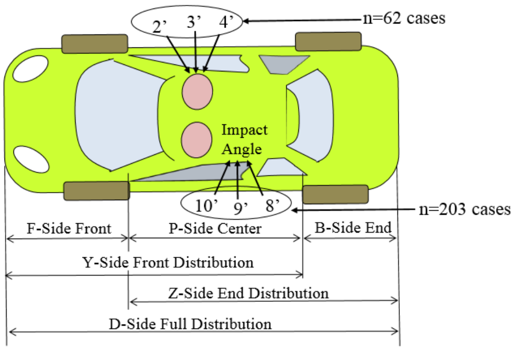


Figure 11. Driver plus passenger cases selection criteria

In order to observe the overall picture of impact location on pelvis injuries, the distribution of AIS2+ (Figure 12) and AIS3+(Figure 13) injuries (based on binary count Yes=1 and No=0) was plotted with respect to the location of maximum external deformation. It is observed that AIS2+ and AIS3+ injuries are more when imapct location is close to B pillar. It is also observed that 80% of serious AIS3+ injuries are coming between -50cm to +50cm. which means more pelvis serious injuries in this region.

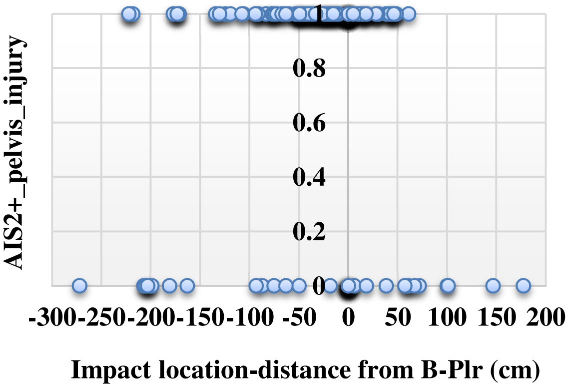


Figure 12. Distribution of AIS2+ injury (binary cases: serious: 1, minor: 0) with respect to impact location-distance from B pillar (cm).

Figure 14 shows the distribution of AIS2+ and AIS3+ injuries with the location of imapct as a continuous variable. It is observed that as the maximum deformation of impact location moves away from B pillar to either left or right of the vehicle, the percentage of injuries were decreasing. The peak values were observed near to B pillar (around driver sitting postion). There was a high chance (AIS2+: 96%, AIS3+:60%) of injury when the imapct location was very close to the driving position near B-pillar.

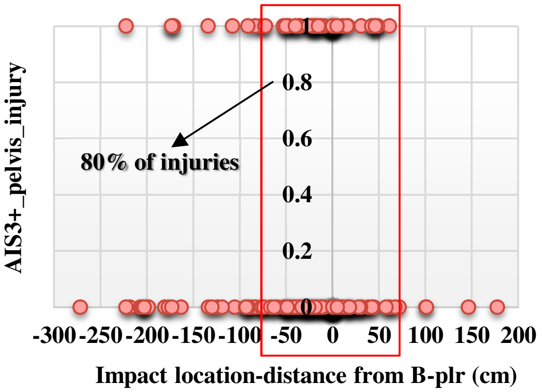


Figure 13. Distribution of AIS3+ injury (binary cases: serious: 1, minor: 0) with respect to impact location-distance from B pillar (cm).

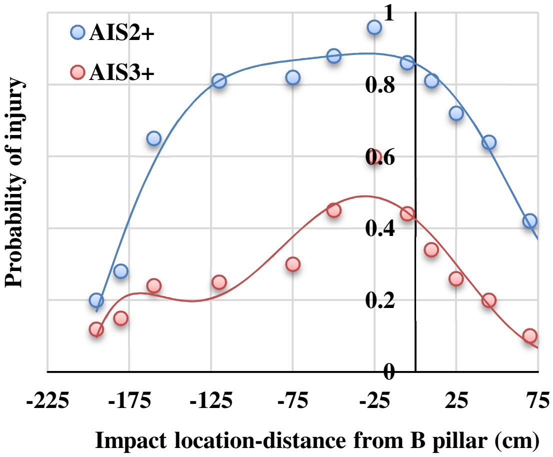


Figure 14. Comparison of probabilities of AIS2+ and AIS3+ injury with respect to impact location-distance from B-pillar (cm) of maximum deformation.

Real world accident data

Figure 15 shows the variation of pelvis injury with respect to various compartment (door inner) intrusion magnitudes 0-8cm, 8-15cm, 15-30cm, and > 30cm.

The X-axis shows different injury levels and Y-axis shows the number of cases considered. All the injury levels are labeled in different categories of intrusion magnitude. It is observed that the risk of pelvis injury increases if the magnitude of intrusion increases beyond a certain level to cause more serious AIS3+ injuries as indicted by two circled portions (①,②).

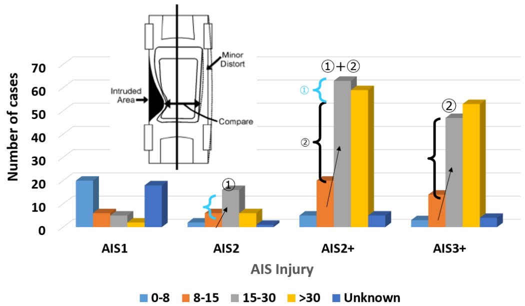


Figure 15. Variation of number of cases (AIS levels) w.r.t compartment intrusion magnitude

Figure 16 shows the probabilities of AIS2+ and AIS3+ injury with respect to intrusion magnitude. As the intrusion magnitude was increasing the probability of both the injuries were increasing. Hence, the magnitude of intrusion is a useful parameter in identfying the injury classification. Figure 17 shows the average intrusion magnitude (AIS2+ and AIS3+) with respect to impact location. It is observed that even though the intrusion magnitude was low near the B-pilllar, AIS2+ and AIS3+ injuries are likely to occur. As the impact location moves further away from B-pillar, either forward or rear side of the vehicle, the average of maximum intrsuion magnitude was increasing in order to cause the same AIS level of injuries.

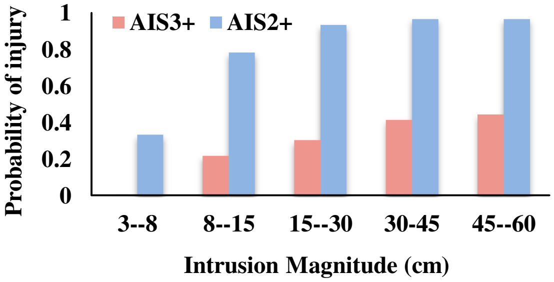


Figure 16. Comparison of probabilities of AIS2+ and AIS3+ injury with respect to intrusion magnitude (cm).

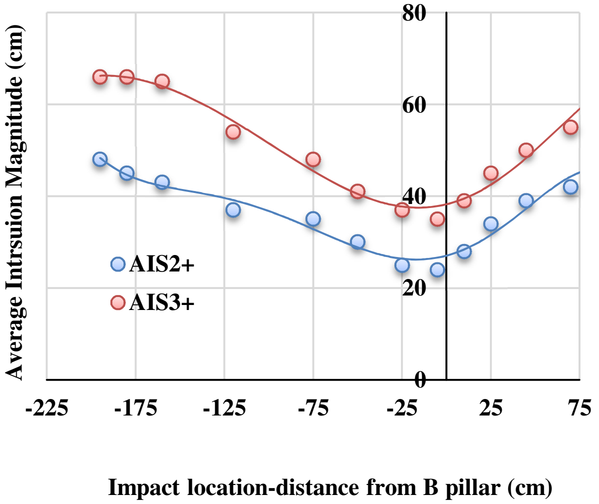


Figure 17 Comparison of average intrusion magnitude for AIS2+ and AIS3+ injury with respect to impact location-distance from B pillar (cm) at maximum external deformation.

Effect of BMI

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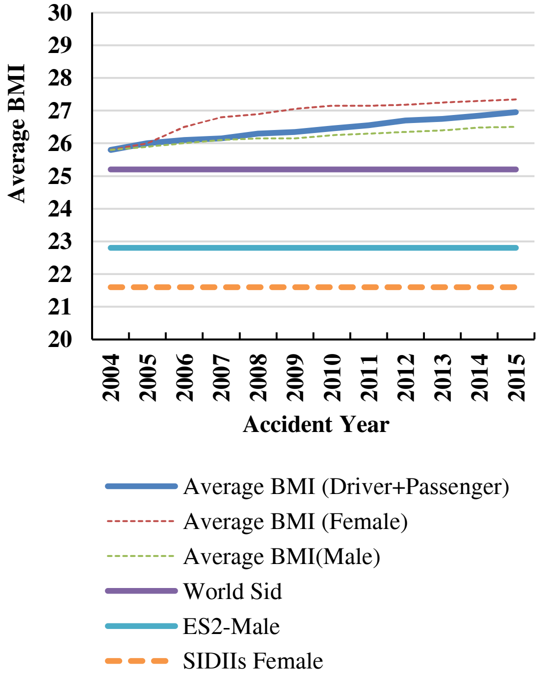


Figure 18 Comparison of Average BMI variation with respect to year of the accident

In order to estimate the effect of BMI on pelvis injuries in a side impact, average BMI was calculated using 11 years of accident data. Figure 18 shows the variation of average BMI of US driving population with respect to the accident year. BMI values of World SID, ES2 Male and SID-IIs female also plotted in the same graph. It clearly captures the increasing trend of average BMI values (average is around 26). In general, the average BMI values of females were greater than that of the male. Hence, BMI can be an infulencial factor for identifying the injury classification. Figure 19 shows the percentage of injuires for below and above the average value of BMI=26.

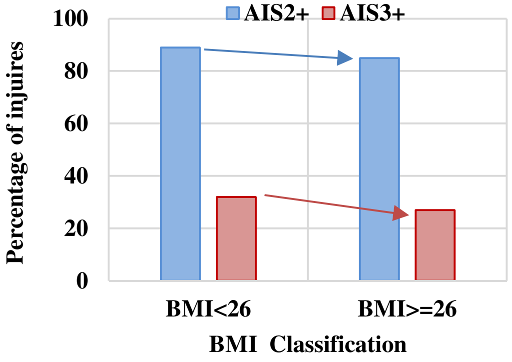


Figure 19 Comparison of AIS2+ and AIS3+ injuries for BMI classification (Average 26)

It is found that the percentage of injuries for <26 was more than >26 which indicates that as the BMI is incresing the percentage of injuries were decreasing. This is may be due to the fact that the relatively shorter and more obese occupants were getting fewer injuires than less obese occupants. As the amount of accumulated fat in pelvis and abdomen region is increasing, there may be less chance of injury in the pelvis region.

Logistic Models (BMI and intrusion magnitude)

In order to find out the effect of BMI and intrusion magnitude, logistc regression models (Table 7 and 8) were developed for both AIS2+ and AIS3+ pelvis injury prediction using the variables such as belt usage (not used:0, used:1) and age (Age<65: 0, Age>=65: 1). In these logistic regression models, total delta-V was splitted into two components as longitudinal and lateral delta-V as continuous variables.

Table 7.
Logistic Model when predicting pelvis AIS3+ injuries when all the variables were considered

n=209 AIS3+: 64, AIS3-: 145 ROC: 0.65	Value	Pr > Chi²	Odds ratio
Intercept	-4.19	0.00	
Longitudinal delta-V	-0.06	***0.04***	0.95
Lateral delta-V	0.02	***0.03***	1.02
Belt not used: 0	0.00		
Belt used: 1	-1.55	***0.00***	0.21
BMI<26-0	0.00		
BMI>=26: 1	-0.85	***0.05***	0.43
Age<65: 0	0.00		
Age>=65: 1	0.91	***0.05***	2.48
Intrusion<15cm: 0	0.00		
Intrusion>=15cm: 1	3.17	***0.01***	23.7

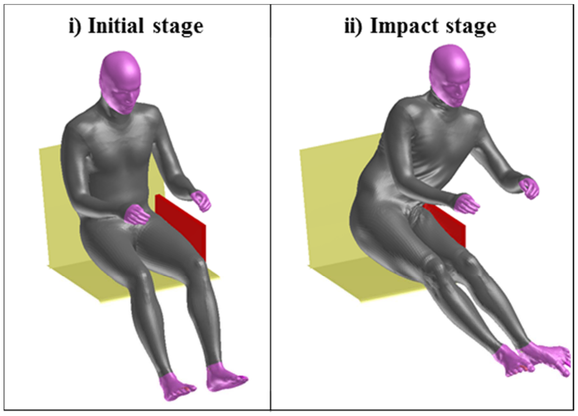
Table 8.
Logistic Model when predicting pelvis AIS2+ injuries when all the variables were considered

n=209 AIS2+: 184, AIS2-: 25 ROC: 0.83	Value	Pr> Chi²	Odds ratio
Intercept	0.29	0.61	
Longitudinal delta-V	-0.10	***0.00***	0.90
Lateral delta-V	0.02	***0.02***	1.02
Belt not used: 0	0.00		
Belt used: 1	-1.58	***0.00***	0.21
BMI<26: 0	0.00		
BMI>=26: 1	-0.43	0.21	0.65
Age<65: 0	0.00		
Age>=65: 1	-0.74	***0.05***	0.48
Intrusion<15cm: 0	0.00		
Intrusion>=15cm: 1	1.21	***0.01***	3.35

As the average BMI is around 26, BMI was categorized into a binary variable (BMI<26: 0, BMI>=26: 1) and the percentage of AIS3+ injury was more than 20% around 15cm of compartment intrusion, the intrusion level was splitted in to a binary variable (Intrusion<15: 0, Intrusion>=15: 1**).** It is observed from the Table 7 that when predicting the AIS3+ pelvis injury, longitudinal component delta-V, lateral component of delta-V, belt-usage, BMI, age and intrusion variables were significant ($p<0.05$). However, when predicting AIS2+ injuries (Table 8) all the variables were significant except BMI ($p=0.21$). In both AIS3+ and AIS2+ predictions, BMI coefficient was negative (-0.85, -0.43) which indicates that as the BMI is increasing, the injury level may be less for occupants of higher obesity. Total delta-V was splitted into two to verify the effect of each individual component. It is observed from both the logistic prediction models that the lateral component is more significant than the longitudinal one. However, they also indicate that in side imapct accident cases, the longitudinal component is also an influential parameter. As ROC value(0.65) is not high for AIS3+ logistic regression (Table7), it needs further investigation. Hence, a non-linear SOM clustering analysis is carried out to verify the results of the above linear logistic cluster analysis and it is discussed briefly in the discussion section. SOM stands for Self Organization Map. It is a neural network based classification technique which can be used efficiently in accident analysis to find out the inherent relationship of complex phenomena (Pal 2017, [17]).

Human body model simulation

To understand the influence of BMI on pelvis injury, human body model (HBM) based impactor simulation was carried out. Based on prior studies (Petit P, 2018, [18] & Matthieu Lebarbé, 2016 [19]) a simple rigid rectangular impactor of size: 400mm x 200mm, mass: 23.4kg & speed: 11.2m/s is used to impact the HBM near pelvis region as shown in Figure 20.


i) Initial stage

ii) Impact stage

Figure 20 Simple sled impactor test near pelvis region with latest GHMBC Human Body Model.

People with high BMI, have more fat/ flesh content in the hip region as explained in the introduction section. To understand its influence on pelvis injury, an additional layer of flesh is added in the hip region of human body model as shown in Figure 21 to represent occupants of slightly higher BMI=30 based on the information of the reference paper [15].

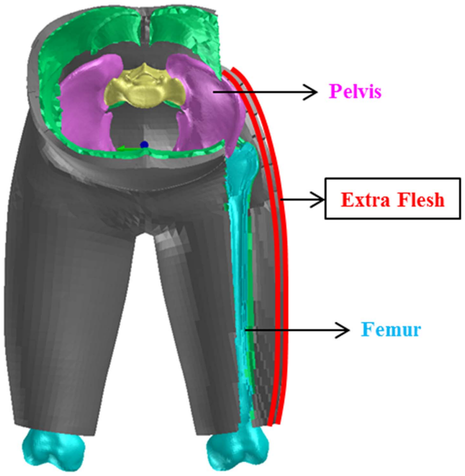


Figure 21 Extra layer of flesh added to hip region of HBM to simulate increased BMI occupant.

Higher BMI human body model with extra outer layer of flesh was impacted against the impactor and the pelvis injury values are compared with the base GHBMC human model. Pelvis bone injury was measured using volume ratio of region which crossed the plastic limit threshold (T*) and the region which do not cross threshold limit. (Note: Threshold T* = one-tenth of GHBMC reference value for fracture). Additional flesh content near the hip region act as a cushion layer to reduce pelvis injury as shown in Figure 22 and Figure A7. Higher BMI is one of the causes of less pelvis ring fracture injury.

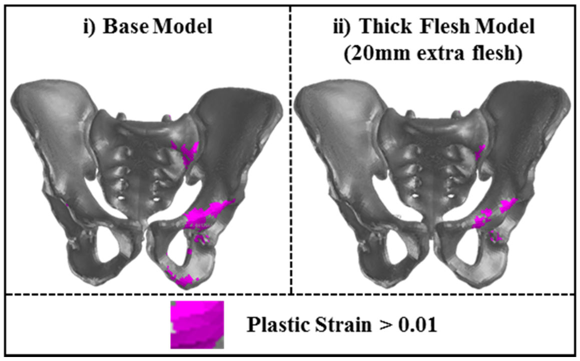


Figure 22 Comparison of pelvis bone injury patterns for base and high BMI thick flesh HBMs

DISCUSSION

The results, as discussed above, suggest that in order to properly evaluate the crash worthiness and occupant performances of different types and sizes of vehicles, it is worth thinking about more rational approach with respect to types and location of structural deformation on the vehicle to identify the actual benefits of existing and future protocols. Collecting more detail intrusion data at relevant different locations near the occupant will be very helpful. Modern camera based image analysis can be one of the possible ways to measure that. In addition to that, EDR data before the crash will add more useful (dimension and depth) of information as future vehicles will be fitted with various sensors.

As the bio-fidelity of the pelvis of SID-2s is low, World-SID is one of the better choices [16]. It is necessary to focus more on evaluating the most frequent pelvic ring fracture by introducing more bio-fidelic dummies equipped with advanced sensors in future protocol tests (refer to Figure A2 and A3). It is also true from the change in BMI trend of US driving population as shown in Figure 18.

To verify the relation between BMI and AIS injury, Self-Organizing-Maps(SOM) based non-linear analysis results were plotted using the pelvis injury input data(refer Figure A4 and A5) related to Tables 7,8. SOM reduces the n-dimensional feature information into 2-dimensional space. The objects (each individual accident case) which are of similar characteristics are placed side by side. The accident cases which are dissimilar are placed further away. A few regions were highlighted using thick black lines to illustrate the effect of BMI on AIS3+ and AIS2+ injury levels in Figures A4 and A5. There are as many numbers of feature based SOM maps as the number of independent input variables of the above mentioned logistic regressions of Tables 7, 8 together with corresponding AIS2+ and AIS3+ injury levels as a dependent variable.

As shown in Figure A4, there were few AIS3+ injuries for BMI>30 within the area surrounded by a thick black line. It indicates that the level of pelvis injury (corresponding to the blue area) will be reduced for obese occupants of older (>65yrs) and younger (<65yrs) occupants. However, there are some small patches of red regions with AIS3+ injury within this thick black line where either the amount of compartment intrusion or the age of the occupants is extremely high. On the other hand, outside the thick black line where AIS3+ SOM map indicates the occurrence of AIS3+ injury (red color), BMI is not that high. These visual clustered results of SOM analysis match well with those of linear logistic regression analysis of Table7.

As shown in Figure A5, the SOM map of AIS2+ injury is clearly clustered in red(AIS2+: 1, yes) and blue(AIS2+: 0, no) regions separated by a thick black closed boundary line marked by ‘a’. The blue part contains a wider range of variations of BMI values and compartment intrusion levels of different accident cases with mixed similarity and dissimilarity patterns. It suggests that BMI (a measure of obesity) is not a definite influential factor for the occurrence of AIS2+ pelvis injury. These visual results of SOM analysis match well with those of logistic regression of Table8. However, one should also note that in the rectangular region as indicated by ‘b’ having AIS+2 injury, there are relatively slim occupants with less BMI (<19), higher compartment intrusion and sitting position very close to B-pillar. This is opposite to the trend of higher BMI obese occupants group as mentioned above. In linear logistic regression analysis, it is difficult to identify correctly such non-linear change in the trend of AIS2+injuries with respect to the change of BMI.

LIMITATIONS

A limited number of cases were studied in this research work. However, considering all possible accident scenarios, more detailed verifications are needed by using various combinations of physical C2C experiments and simulations using different dummies and types of vehicles in order to make any generalized statement as stated above. It is also necessary to do a similar accident analysis for other countries having good accident database for further verification.

CONCLUSION

This paper discussed the sensitivity of the pelvis injury patterns of C2C side impact accidents at the intersection for PV vehicles using NASS-CDS CY 2004-2015 data. From the accident analysis it was revealed that a) pelvic ring fracture is one of the most frequent injuries, b) 10 o'clock impact caused the highest number of injuries, c) pelvis injury frequency is higher in female than male, d) risk of pelvis injury increases when the maximum intrusion of B-pillar and surrounding door structure exceeds a centain level.

It is also verified using HBM simulation that higher BMI>30 obese occupants will probably have less chance of AIS+3 injury when compared with those of normal occupants with BMI<26 in similar severity of C2C intersection impact. Non-linear SOM cluster analysis supports the effect of BMI on pelvis injury.

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NOMENCLATURE:

AF05: 5th percentile American female
AIS: Abbreviated Injury Scale (1998 version)
AM50: 50th percentile American male
C2C: Car to Car
BMD: Bone mineral density, the mass of mineral per volume of bone
BMI: Body Mass Index, the measure of body fat based on height and weight
IIHS: International Institute of Highway Safety
NCAP: New Car Assessment Program
NASS-CDS: National Automotive Sampling System Crashworthiness Data System
PV: Passenger Vehicle
SOM: Self Organization Map
SUV: Sports Utility Vehicle

APPENDIX A.

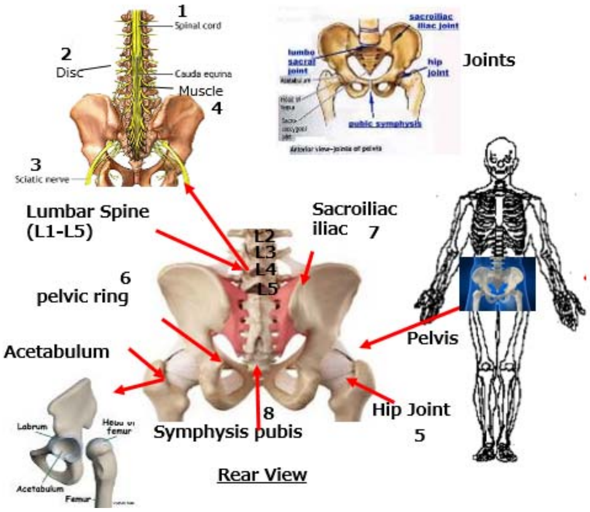

Figure A1. Schematic view of the pelvis region

Table A1.
Distribution of injuries in each part of the pelvic body structure

		AIS1+	AIS2+	AIS3+
All body region (AIS98 code)	***Injury code***	4195	1408	709
Lumbar spine				
1.Cord	640601	52	0	0
2.Disc	650699	40	40	0
Lower extremity				
3.Sciatic nerve	830476	2	2	0
4.Muscle tear	840604	2	0	0

5.Hip (Acetabulum; femur head)	850699	4	0	0
6.pelvic ring fracture	852602	176	176	57
7.Pelvis Sacroiliac fracture	852800	2	2	2
8.Symphysis pubis fracture	853000	13	13	13
Lumbar spine + Lower extremity related pelvis injury		***291 (7.1%)***	***233 (16.5%)***	***72 (10.2%)***

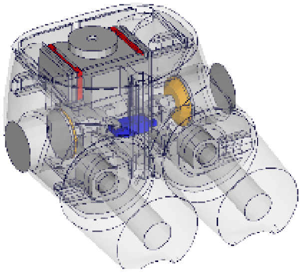

Figure A2. Schematic view of SID-IIs pelvis

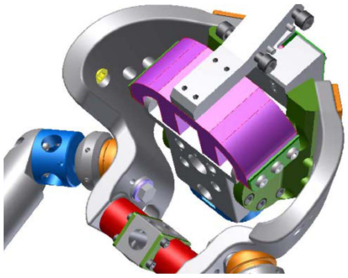

Figure A3. Schematic view of World-SID pelvis

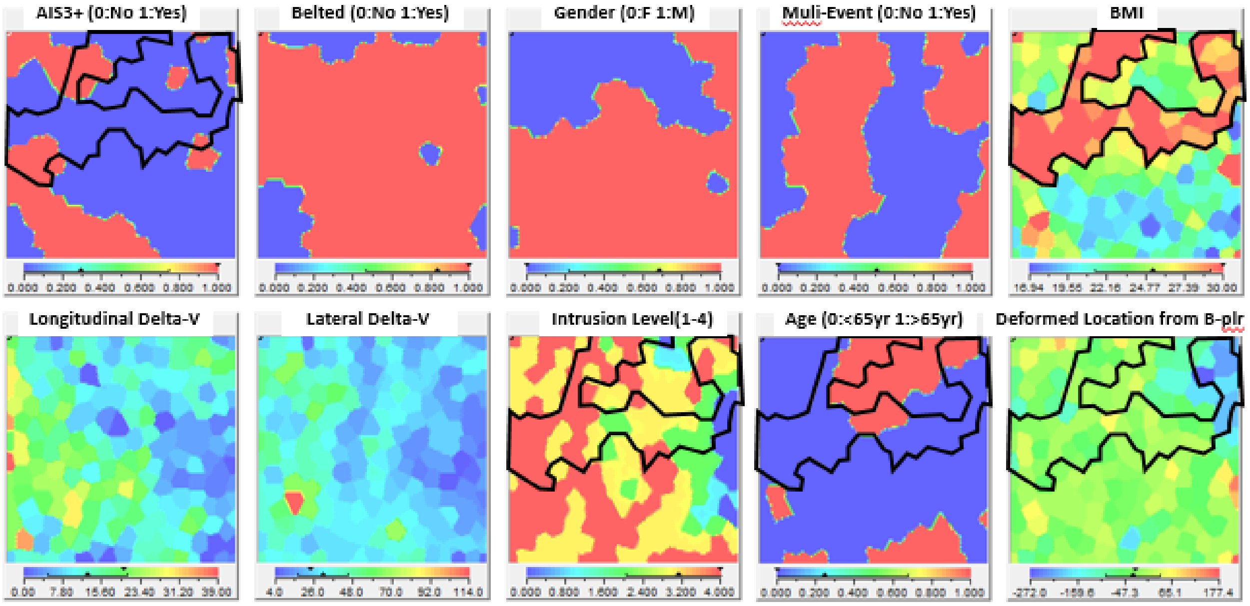

Figure A4. Self-Organizing-Maps (SOMs) of AIS3+ pelvis injury (10 attributes with 10 maps) to visualize the nonlinear relationship of the variables of the linear logistic regression analysis of Table 7. At the bottom of each SOM map, the red and blue scale bars indicate the corresponding highest and lowest values of corresponding variables.

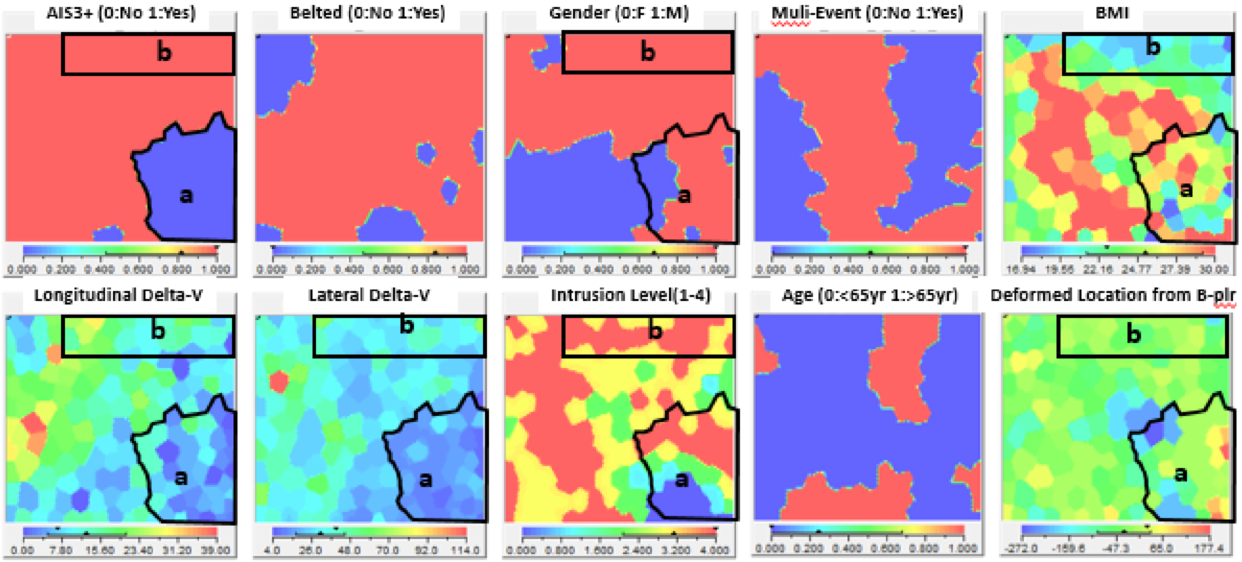

Figure A5. Self-Organizing-Maps (SOMs) of AIS2+ pelvis injury database (10 attributes with 10 maps) to visualize the nonlinear relationship of the variables of the linear logistic regression analysis of Table 8. At the bottom of each SOM map, the red and blue scale bars indicate the corresponding highest and lowest values of corresponding variables.

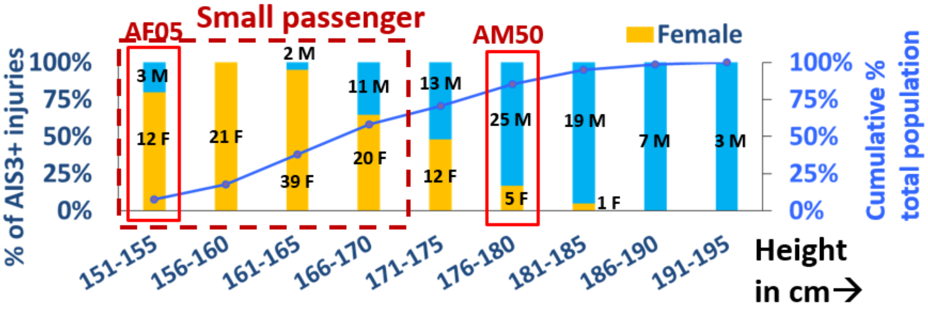

Figure A6. Distribution of occupant height in cm

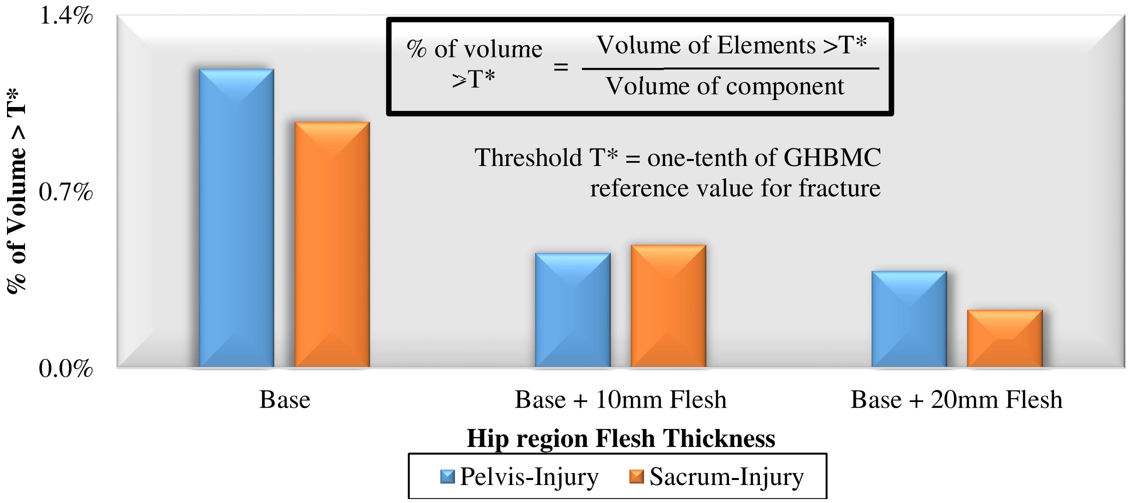

Figure A7. Influence of hip region flesh thickness on pelvis injury